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Long-Term Green Space Exposure and Cognition Across the Life Course: a Systematic Review

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Abstract An accumulating body of evidence is suggestive for health-promoting effects of exposure to natural environments including green spaces. We aimed to systematically review the available observational evidence on the association between long-term exposure to green space and cognition over the life course. PubMed and Scopus were searched using a combination of green space and cognition keywords. Original research articles of observational studies on the association between green space exposure and cognition were collected. The quality of available studies was assessed using available frameworks. The review identified 13 studies meeting the selection criteria. Considering the limited number of available studies, most of poor or fair quality, the existing evidence on the association between green spaces and cognition can be considered as inadequate; however, it is suggestive for beneficial associations between such an exposure and cognitive development in childhood and cognitive function in adulthood.

Keywords Green space · Cognition · Attention · Life course · Built environment · Dementia

Background

Currently, around 50 % of the population live in cities worldwide, and it is predicted that by 2050 almost 66 % of the global population will live in urban areas [1] where residents often have limited access to natural environments in their daily lives. An accumulating body of evidence is suggestive for health-promoting effects of exposure to natural environments including green spaces [2]. Experimental studies on short-term effects of nature experience have shown positive associations with mental status including improved mood [3], restored attention [4], and reduced stress [5]. Furthermore, observational studies have associated long-term exposure to residential greenness with improved mental health [6] and reduced morbidity [7] and mortality [8].

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Green space exposure is thought to play a pivotal role in cognitive development at early stages of life [9, 10], which in turn affects the cognitive function in adulthood and, ultimately, cognitive decline in elderly [11]. There is therefore a need to evaluate the impact of green space exposure on cognition through the life course covering all different stages of life. Although there are a number of reviews that associate exposures to physical environment to cognition, none has focused on the association between long-term exposure to green space and cognitive function through the life course with long-term exposure to greenness over a longer time period (i.e., months, years) for example when surrounding the home, school, or work place. Generally, reviews have included a broad range of exposures from the built or social environment [12, 13] with natural environments being only one of the exposures that were briefly touched upon. Therefore, the aim of this review was to systematically evaluate the current available body of observational evidence on the association between long-term exposure to green space (including parks, gardening, etc.) and cognition over the life span.

Methods

Search Strategy and Selection Criteria The checklist of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was applied to guide the review process [14]. We used MEDLINE (National Library of Medicine) and Scopus (Web of Science) to search for relevant articles.

This review included a three-step search approach. First, MEDLINE was searched freely to identify some first relevant articles. The keywords of these articles were investigated in order to create an extensive list of keywords. Eventually, the search terms included a combination of cognition keywords and green space keywords. For cognition, the following keywords were applied: cognition, cognitive, cognitive decline, cognitive performance, cognitive development, cognitive function, cognitive dysfunction, cognitive impairment, cognitive deterioration, Alzheimer, dementia, memory, concentration, communication, orientation, neurodevelopment, learning, academic performance, academic achievement, academic attainment, school performance, student performance, educational attainment, and educational achievement. For green space, the keywords included were green space or greenspace, greenery, greenness, natural environment, neighbo(u)rhood environment, built environment, urban green, urban design, park, garden, vegetation, yard, forest, land use, and urban environment.

Second, MEDLINE and Scopus were searched based on a combination of all keywords. The search was restricted to articles in the English language and human studies. All articles up to May 26, 2016 (date we conducted the search), were included. Third, the reference lists of relevant articles found in our search were checked to find additional studies. The selection criteria were as follows: (a) at least one of the exposures was a measure of green spaces or natural environment exposure, including outside activities in green spaces such as gardening. Studies solely comparing rural to urban areas were excluded, because many factors other than green space might have affected the results. (b) At least one of the outcomes was a measure of cognition, attention, dementia, or Alzheimer. Outcomes such as stress, relaxation, mood, and mental health (when not combined with a measure of cognition) were excluded. (c) Original research articles of observational studies were included, whereas review articles, experimental studies, and qualitative studies were excluded. (d) Studies on all age groups were included.

After inserting the searched articles into Rayyan [15], an online tool that facilitates the management of selected articles, we conducted a first screening based on the title and then the abstract of the articles. Afterward, the full texts of the articles selected based on the title and abstract were studied to decide which one met the selection criteria and could therefore be included in the review.

Quality Assessment First, the following data was extracted from the selected studies: author, year of publication, country, study design, study population, sample size, exposure assessment, outcome assessment, confounding factors, statistical analysis, main outcomes, and other relevant information (Table 1 and Supplemental Table S1). To evaluate the evidence, the articles were given a quality score based on 11 criteria adapted from a systematic review of the impact of long-term exposure to green space on mental health by Gascon et al. (2015) (Supplemental Table S2) [6, 16]. Two reviewers conducted the quality assessment independently and discussed points of disagreement to harmonize the grades. For each of the 11 criteria, between 0 and 1 or 2 points were given. Subsequently, the sum of these points was converted to a percentage of the maximum score (=14). The percentage indicates the quality with ≥81 % as *excellent quality*, between 61 and 80 % as *good quality*, between 41 and 60 % as *fair quality*, between 21 and 40 % as *poor quality*, and ≤20 % as *very poor quality* [6, 16].

Evaluation of the Evidence We applied the guidelines for the level of evidence used by the International Agency for Research on Cancer (IARC) and adapted by other reviews similar to this review [6, 17] to classify the evidence for a causal relationship between the exposure and outcome. Accordingly, evidence was labeled as *sufficient* if most of the studies, including good quality studies, reported an association, but evidence was not yet conclusive enough to ascertain that there is a causal relationship. Evidence was classified as *limited* when several good-quality, independent studies reported an association, but evidence was not yet conclusive

Table 1 Main characteristics of selected articles on green space and cognition

Author (year, country)	Study design	Study population	Number	Greenness data source	Greenness indicator	Outcome assessment	Outcome	Main results
Children								
Wells 2000, USA [18]	Longitudinal	Children from low-income urban families	17	Self-reported greenness	Naturalness scale	Attention deficit disorders evaluation scale (ADDES)	Attentional capacity	Regression coefficient 29.6 (SE = 9.8) for postmove attentional capacity (increase in ADDES) by an increase of naturalness scale of the home
Taylor et al. 2001, USA [25]	Cross-sectional	Children diagnosed with ADD or ADHD of age 7–12	96	Parent-reported classification of physical settings of activities	Classification as green setting	Parent-reported symptoms of inattention	Severity of symptoms of inattention	Activities in a green setting were correlated to lessened attention deficit symptoms
Kuo et al. 2004, USA [26]	Cross-sectional	Children diagnosed with ADHD of age 5–18	452	Parent-reported classification of physical settings of activities	Green outdoor setting	Parent-reported ADHD symptoms	Severity of ADHD symptoms	Green setting of (same) activities correlated to reduced symptoms of ADHD
Matsuoka 2010, USA [21]	Ecological	Public high schools	101	Rating of naturalness by principal researcher (1–4) Acreage of athletic fields, parking lots and landscaped areas Building window size and school policy on length and place of lunch	Ratings of views of nature Vegetation levels on campus Access to vegetation	Michigan merit award, graduation rates and rate of student with 4-year college plans	School-level academic achievement	Regression coefficient 0.14 for Michigan merit award proportion with increasing views of nature ratings Regression coefficient 0.17 for graduation rates with increasing views of nature ratings
Wu et al. 2014, USA [22]	Ecological	Public elementary schools	905	NDVI	Surrounding greenness of schools	Composite Performance Index	School-level measure of student performance	Regression coefficients in March[a] for a 250-m NDVI buffer: 0.19 (95 % CI 0.16, 0.21) for English 0.20 (95 % CI 0.16, 0.23) for Math
Dadvand et al. 2015, Spain [20•]	Longitudinal	School-children of age 7–10	2623 (2593 complete answers)	NDVI	Surrounding greenness of schools, homes, and commuting route	Computerized n-back test and attentional network test	12-month change in working memory and attention	An IQR increase in total surrounding greenness index was associated with an increase in the progress of working memory of 5 % and a reduction of inattentiveness of 1 %.
Adults								
Tennessen et al. 1995, USA [23]	Cross-sectional	Residents of university dormitories (age 18–25)	72	The naturalness of views from windows were rated by independent subjects (1–4)	Naturalness scale	Performance on the Digit Span Forward and Backward test, the Symbol Digit Modalities Test, the Necker Cube Pattern Control Test, and the	Direct attentional capacity	Having natural views from dormitory windows was correlated to better direct attentional capacity

Table 1 (continued)

Author (year, country)	Study design	Study population	Number	Greenness data source	Greenness indicator	Outcome assessment	Outcome	Main results
						Attentional Function Index		
Kaplan 2001, USA [24]	Cross-sectional	Residents	188	View content, and satisfaction with views	Presence of landscaped areas, trees, parks, mowed areas, and farms or fields	Self-reported mental fatigue (5-point scale)	Distraction item	Regression coefficient −0.18 for distraction comparing presence of trees in the view to absence. Regression coefficient −0.17 for distraction comparing presence of farm or field in the view to absence
Bodin et al. 2015, Sweden [29•]	Cross-sectional	Residents (age 18–79)	2612	Self-reported view from the window	Windows facing green space	Self-reported problems to concentrate (5-point scale)	Difficulty to concentrate	OR 0.76 (CI 0.61, 0.95) for concentration problems (having windows facing green space VS not having views of green space)
Older adults								
McCallum et al. 2007, Australia [19]	Longitudinal	Non-institutionalized residents[b] of age >60	2805	Daily vs rarely gardening	Gardening	First recorded presentation of dementia	Dementia	HR 0.64 (CI 0.50, 0.83) for dementia (daily VS rarely gardening)
Prohaska et al. 2009, USA [27]	Cross-sectional	Residents of age ≥65 (at least 1 year of residence)	884	Self-reported place of walking	Parks	A modification of the Mini-Mental State Examination and the Mental Alternation Test (in-person interview)	Cognitive function	Regression coefficient $\beta = 1.00$ (SE = 0.50) for Mental Alternation Test score for increase in walks in parks
Clarke et al. 2012, USA [28•]	Cross-sectional	Residents of age ≥50	949	Land cover in census tract	Park area per square mile	Telephone Instrument for Cognitive Status (telephone interview)	Cognitive function	Did not find significant effect of park area on cognition
Wu et al. 2015, UK [30]	Cross-sectional	Population of age ≥65	2424	Percentage of surrounding green space and private gardens	Quartiles of naturalness	Mini-Mental State Examination and the Geriatric Mental Status (in-person interview)	Cognitive impairment and dementia	OR 1.41 (CI 1.00, 1.98) for cognitive impairment and 2.23 (CI 1.17, 4.24) for dementia (highest VS lowest quartile of the natural environment)

[a] Results using measurements from months July and October were also provided. Measurements in March gave the strongest associations with student performance

[b] Not living in nursing homes or other care institutions

enough. When the association was reported by one or more studies, but with insufficient quality, inadequate numbers of studies, lack of consistency, and/or lack of statistical power precluded a conclusion regarding the presence or absence of a causal relationship, this was classified as *inadequate* evidence. Last, when several good-quality studies were consistent in showing no causal relationship, this was classified as *evidence for lack of association.* This categorization was conducted separately for children (7–18 years), adults (>18 years), and older adults (>50 years).

Results

Study Selection A total of 9315 articles were found by the systematic search through MEDLINE and SCOPUS (Fig. 1). By reviewing the titles, 513 articles were selected for abstract reviewing of which 89 were duplicates. Additionally, eight articles were identified from the references of relevant articles. Subsequently, we read the abstract and found 64 articles relevant for reviewing the full text. After applying the selection criteria, 13 studies were identified to be qualified and were included in the review.

Study Characteristics Three longitudinal [18, 19, 20•], two ecological [21, 22], and eight cross-sectional studies [23–27, 28•, 29•, 30] were among the selected articles. Most studies were from the USA [18, 21–28], three from Europe (Sweden [29•], Spain [20•], and UK [30]), and one from Australia [19]. Table 1 presents the main characteristics and results of these articles. The sample sizes ranged from 17 to 2623 participants, with six studies on children [18, 20•, 21, 22, 25, 26], three studies on adults [23, 24, 29•], and four studies on older adults [19, 27, 28•, 30].

The studies were heterogeneous in terms of the assessment of exposure and outcome. Green space was assessed both by objective and subjective measures. The objective measures included (1) neighborhood measures of the percentage of green space [30] and park area [28•] and (2) greenness surrounding schools [21, 22], or schools, homes, and commuting route between the two [20•], using satellite-based Normalized Difference Vegetation Index (NDVI) (i.e., photosynthetically active green land cover) to quantify greenness [20•, 22], aerial photographs [21], or tree counts through surveys [21]. Subjective measures included ratings of greenness [18, 24, 25], self-reported [29•] or surveyed [21] views of green space through the window (i.e., visual access to green space), and reporting of the settings for their activities [19, 26, 27].

The outcomes were cognitive development [20•], cognitive function [23], cognitive decline or impairment [27, 28•, 30], distraction and concentration problems [24, 29], symptoms of inattention [18, 25, 26], measures of school performance [21, 22], and dementia incidence [19]. Five studies used objective measures of cognition (cognitive tests [20•, 23], recording incidence of dementia [19], and aggregate measures of school performance [21, 22]). Validated questionnaires were used in three studies; the participants were interviewed in person using the Mini-Mental State Examination [27, 30] or through telephone using the Telephone Instrument for Cognitive Status [28•]. The remaining five studies used subjectively measured outcomes by self- or parent-reported measures [18, 24–26, 29•].

Study Findings

Children Four of the six studies conducted in children investigated the association between the school or residential surrounding greenness and school performance, cognitive development, or attentional capacity in children [18, 20•, 21, 22] (Table 1). All four studies reported a beneficial association between green space exposures and these outcomes. In a longitudinal study of a Spanish cohort of school children (N = 2623), an increase in greenness (i.e., NDVI average) surrounding home, school, and commuting route between these two was associated with an enhanced progress of working memory and a reduction of inattentiveness during the 12-month course of the study [20•]. The two ecological studies found a positive association between views of nature through the cafeteria window and school-level scores on standardized tests and graduation rates [21] and between school surrounding greenness and school-level academic achievement in English and Math [22]. In a cohort of children of low-income urban families from the US (N = 17), the attentional capacity was reported by the parent before and “several months” after moving to a house with more greenness [18]. An improvement in direct attention was found in children who moved to a home with higher “naturalness” compared to children who moved to a home with less naturalness. Additionally, two other studies from the USA found a protective effect of green space exposure on the severity of symptoms of attention deficit hyperactivity disorder (ADHD) and attention deficit disorder (ADD) in children diagnosed with these disorders [25, 26] (Table 1).

Adults Three cross-sectional studies on adults focused on visual access to green space through windows of the place of residence as the measure of exposure [23, 24, 29•]. In a survey of the residents of the city Malmö, Sweden, reduced odds of concentration problems were found in people who had a window facing green space compared to people who did not have a window facing green space [29•]. Furthermore, the presence of trees and the presence of a farm or field in the window view were associated with a decrease of distraction measures in a survey of low-income residents of Michigan, USA [24]. Additionally, having natural views from dormitory

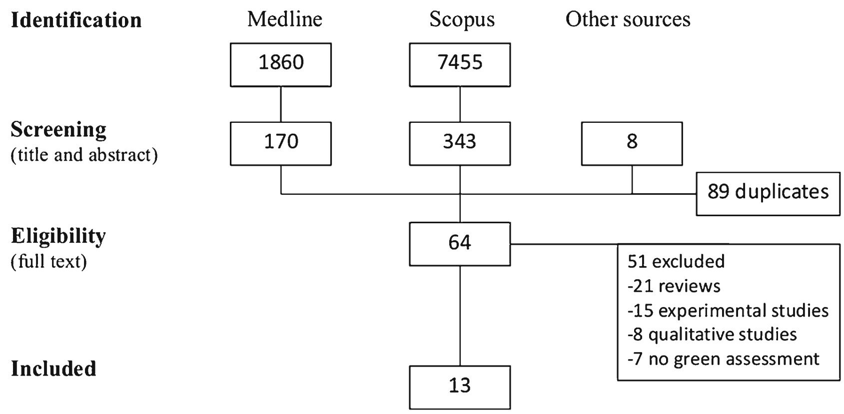

Fig. 1 Selection process of the articles

windows was found to be correlated to better results in tests of directed attentional capacity in 72 university students from a large Midwestern university in the USA [23] (Table 1).

Older Adults Two cross-sectional studies investigated the association between neighborhood naturalness and cognition in older adults [28•, 30]. The first study included face-to-face interviews with residents of the city Chicago, USA, and found no association between the proportion of park area in the residential neighborhood and cognitive functioning [28•]. The other study found a positive association between the percentage of surrounding green space and private gardens and cognitive impairment in older adults in England [30]. Two other studies used the settings of walking and gardening as predictors of cognitive functioning in elderly and dementia [19, 27]. The first, of cross-sectional design, was based on interviews with older adults from California, Illinois, Pennsylvania, and North Carolina in the USA and found that walks in the park were associated with improved cognitive function as quantified by the Mental Alternation Test, while walking in non-natural settings such as shopping malls or gyms did not show such an impact [27]. Finally, in a longitudinal study among residents from the Dubbo Local Government Area, a major semi-urban center in Australia, a reduced risk of dementia was found comparing daily gardening to rarely gardening [19] (Table 1).

Evaluation of the Evidence Five studies were classified as of fair quality, five as of poor quality studies, and three studies as of good quality (Supplemental Table S3). All studies focusing on children reported an association, supporting beneficial effects on cognition of exposure to green space with only one study being of good quality [20•]. We considered this as limited evidence. For adults, only studies of poor quality were found, but they were consistently suggestive of a positive association between green space exposure and cognition, resulting in inadequate evidence. Of the studies on older adults, two were of fair quality [28•, 30] and two of good quality [19, 27]; however, the results were inconsistent between studies, thus we considered the evidence to be inadequate.

Discussion

In this review of observational studies, we found inadequate but suggestive evidence for a positive association between long-term green space exposure and cognition over the life course.

Limitations of Available Evidence

This review was limited by a small number of studies available, which together with the lack of longitudinal studies disallows establishing a causal link. Additionally, the studies used heterogeneous methods for exposure and outcome assessment making comparison of their findings complicated.

Study Design Most of the included studies were of cross-sectional design, which limits the capability for establishing a causal link as cross-sectional studies cannot rule out reverse causation or precedence of the outcome to exposure. These studies are also prone to selection bias, if, for example, older adults with cognitive impairments move to neighborhoods with more supportive environmental exposures. This could be a potential explanation of some results in the cross-sectional study by Wu et al. (2014), where green space appeared as a risk factor for cognitive impairment and dementia [30].

Exposure Assessment Ideally, the exposure assessment of green space should cover different aspects including use of green spaces, physical and visual access to green spaces, and surrounding green space at different microenvironments (e.g., home, workplace, school, and commuting routes) while taking account of the quality of green space and vegetation types. The studies included in this review lacked many of these aspects in their exposure assessment. For instance, use of green space was recorded by only one study [24]. Additionally, two studies recorded walking in parks or gardening occasions, but these did not include any measure of greenness of the location. None of the studies considered physical access to green space, and only visual access to green space was evaluated in some of the studies [21, 23, 24, 29•]. Furthermore, surrounding greenness was objectively measured by five studies [20•, 21, 22, 28•, 30], but were limited to school or home surrounding greenness, with one study considering the greenness of both and the commuting route between the two [20•]. Lastly, no study addressed the potential influence of the quality of green space on the analyses, although one study inquired about the level of satisfaction with the neighborhood and nature [24]. Quality characteristics of green spaces such as safety, esthetics, biodiversity, walkability, sport/play facilities, and organized social events have been suggested to affect the use of green spaces [31]. Several tools are developed to assess the quality of green spaces. An example is the Neighborhood Green Space Tool (NGST), a simple tool that independent observers can use to assess the quality of neighborhood green spaces in the domains of access, recreational facilities, amenities, natural features, incivilities, and usage [32].

Outcome Assessment Ideally, cognitive functioning would be measured by computerized tests [33] or assessments by healthcare professionals. However, only two of the included studies used objective cognitive tests: the computerized n-back test to assess working memory and the Computerized Attentional Network Test to evaluate attention in primary school children [20•], and the Digit Span Forward and Backward test, the Symbol Digit Modalities Test, the Necker Cube Pattern Control Test, and the Attentional Function Index to assess attentional capacity [23]. Most of the included articles were based on self- or parent-reported cognitive function. Although some studies used well-established questionnaires such as the Mini-Mental State Examination [27, 30], others used questionnaires developed by the authors which were not necessarily validated [24, 26]. Furthermore, the two ecological studies used aggregated measures of school performance, which, first, were prone to ecological fallacy, and second, could have been affected by residual confounding, because although attentional capacity has an important influence on school performance [34], school performance is also affected by many other factors that not all have been adjusted for.

Control for Confounding Although all studies except one [23] adjusted for a measure of socioeconomic status (SES), the possibility of residual SES confounding cannot be ruled out. SES has been shown to have an effect on health in different levels where individual and neighborhood SES have independent associations with the susceptibility of individuals to disease [35, 36]. Merely three studies [20•, 28•, 30] controlled their analyses for SES at both individual and area levels, and the two ecological studies only controlled for school-level SES. Confounding also remained a possibility in the studies on activities (walking in green spaces and gardening) [19, 27] in which it is uncertain whether the effect is partially explained by green space exposure during the activity or due to physical activity itself or other factors such as leisure or social networking. However, in two studies on older adults, walking in other settings than parks or physical activities other than gardening showed smaller or no protective effects [19, 27]. Moreover, effect modification was not investigated in any study, although this might be important. For example, the association between green space and health is suggested to vary over the strata of socioeconomic status [37], age, gender [38, 39], and degree of urbanity [40, 41]. The association has been found to be generally stronger among lower socioeconomic groups [37] and for people living in urban areas [41]. Combining these two aspects, some found no association among people living in the higher-income suburban areas [40]. However, the modification of health benefits of green spaces by the degree of urbanity seems to be context-specific with some studies not supporting such a modifying role [42]. The available evidence on the modifying role of sex on health benefits of green spaces is suggested to vary by age with some studies showing the benefits to be more relevant in boys among children [43–45] and in women among older adults [38, 39].

Reporting the Associations Three studies did not report the effect size [23, 25, 26] and three studies did not provide the confidence intervals [21, 24, 28]. It was therefore not possible to explore the publication bias through formal tests (e.g., funnel plot).

Mechanisms

The pathways through which green space exposure could exert benefits on cognition are not fully understood, but several mechanisms have been proposed. First, the *Attention Restoration Theory* proposes that contact with nature provides the opportunity to restore directed attention after being overused by numerous attentional tasks accompanying urban life [4, 46, 47]. Second, higher levels of physical activity have been demonstrated in areas with higher access to green spaces for the general population [48] and for older adults [49] and children [50]. Physical activity has been suggested to enhance cognitive development in children [51] and offer protection for cognitive decline in older adults [52]. Additionally, green space in residential environments could lead to less loneliness and more social support [53]. In this sense, several studies have shown the benefit for cognitive function of social engagement in older adults [13]. Last, green space has the potential to decrease exposure to air pollution [54] and noise [55], the exposures that have been associated with diminished cognitive development [56–59] and enhanced cognitive decline [60, 61].

Only two of the 13 studies included in this review investigated potential pathways; one study considered mediation by physical activity and social integration, but did not find any notable mediation effect [28•]. Another study tested mediation by air pollution and found that indoor levels of elemental carbon explained 20–65 % of the association between green space and cognitive development in school children [20•]. To establish a causal link between green spaces and cognition, it is highly recommended for future studies to include mediation analyses, specifically for social integration, depression, air pollution, noise, and physical activity.

Conclusions and Recommendations

In a highly urbanizing world, the availability of green space could represent major benefits to health of urban residents. The existing body of evidence on the association between green spaces and cognitive function through the life course is still inadequate; however, it is suggestive for beneficial associations between such an exposure and cognitive development in childhood and cognitive function in adulthood. Results for an association with cognitive decline in older adults have been inconsistent. The findings of the articles included in this review call for further investigations, especially those that (1) apply robust designs such as a longitudinal design; (2) cover different aspects of exposure to green spaces; (3) objectively assess cognitive functions using computerized tests or conduct assessments of cognitive function by healthcare professionals; (4) investigate potential pathways underlying the association between green space exposure and cognitive function; and (5) explore the modification of such an association by socioeconomic status, ethnicity, urbanity, and climate/vegetation cover.

Compliance with Ethical Standards

Conflict of Interest Carmen de Keijzer, Mireia Gascon, Mark J. Nieuwenhuijsen, and Payam Dadvand declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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